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RECENT PUBLICATIONS

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By R. Dixon, B.Sc. and E. A. Spackman, M.Sc.

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By G. R. R. Benwell, M.A., A. J. Gadd, Ph.D., J. F. Keers, B.Sc., Margaret S. Timpson, B.Sc., and P. W. White, Ph.D.

A full description is given of the 10-level numerical weather prediction model which has been developed by the Meteorological Office during the past few years for use in investigating the dynamics of fronts and in predicting rainfall. The formulation includes representation of the effects of surface friction, topography, surface exchanges of sensible and latent heat, sub-grid-scale convection, and lateral diffusion. An example of a recently computed forecast is included.

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AN OBJECTIVE METHOD OF FORESHADOWING WINTER RAINFALL AND TEMPERATURE FOR ENGLAND AND WALES

By R. MURRAY

Summary. Nearly 100 years of monthly mean pressure anomaly data for the northern hemisphere are analysed in order to pinpoint areas where anomalous circulation features in the autumn are of importance in determining the broad type of winter weather over England and Wales. Simple indices of anomalous circulation in key areas are combined to produce several useful and objective rules for predicting mean winter temperature over England and winter rainfall over England and Wales. On many occasions useful indications of winter rainfall and/or temperature are shown to occur in early autumn. Even better and more generally applicable predictive rules are presented on the basis of anomalous circulation features in the three autumn months.

Introduction. The economic value to the community of accurate forecasts of winter temperature and rainfall is obvious. Even the prediction for the 3-month period from December to February of mean temperature and total precipitation in the rather broad classes of quintiles and terciles respectively would be enormously useful to the transport, fuel and building industries, to agriculture and to the general public.

In recent years some experimental work has been done in the British Meteorological Office on seasonal foreshadowing, as recently reported by Murray.[1] Hay[2] has suggested that October is a key month for predicting winter temperature over central England in the so-called 'blocked' epoch (1873–95 and since 1940) but his results were not satisfactory in the 'westerly' epoch (1896–1939). Hay[3] also showed that rainfall over Britain in the early autumn was a useful indicator of winter temperature under certain circumstances. Murray[4] drew attention to some associations between rainfall and temperature in the winter and preceding months.

The present paper is mainly concerned with describing and illustrating objective forecasting procedures derived from analysing mean monthly pressure anomalies over the northern hemisphere preceding various types of winter; some synoptic climatology of relevance in seasonal foreshadowing is also presented.

Large-scale mean surface pressure anomaly patterns are closely related to broad-scale anomalous circulations near the surface and also to anomalous circulation in the middle troposphere. Indeed, Sawyer[5] recently drew attention to the high correlation between the mean geopotential at 1000 mb

and that at 500 mb on the monthly time-scale, especially over the Atlantic–European sector. There is also a practical attraction in exploiting mean pressure since the Meteorological Office holds such data in conveniently processed form on magnetic tape, with adequate completeness over the northern hemisphere back to 1873. However, perhaps the main reason for attempting to extract the maximum information from monthly mean pressure anomaly data is the belief that there must be some pattern in the behaviour of anomalous circulation between autumn and winter, reflecting many complex feedback processes. Studies of the ways in which the broad-scale circulation patterns have developed and evolved in the past must be rewarding in view of our present ignorance, but such investigations are themselves difficult and time-consuming even when carried out for particular case-studies. The present empirical approach was concerned with picking out in the autumn months those key areas where anomalous circulation features seem to show some relationship with winter rainfall or temperature. Then several simple but objective relationships of predictive value were developed.

In this paper the central England mean winter temperature is taken from Manley's[6] compilation and the general rainfall over England and Wales refers to the long series of rainfall records maintained by the Meteorological Office. The percentile boundaries employed are based on the 90-year period 1874 to 1963; the rainfall terciles are given by Murray[4] and the temperature quintiles by Murray.[7]

Circulation, rainfall and temperature in winter. The average winter circulation may be represented by the mean surface pressure map for the 3-month period December to February based on data from 1873 to 1968, shown in Figure 1. The mean pressure anomaly map in Figure 2(a) represents

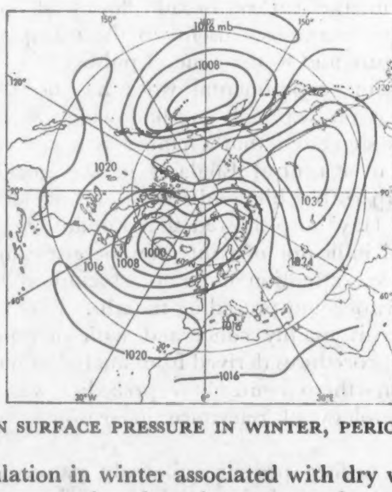

FIGURE 1—MEAN SURFACE PRESSURE IN WINTER, PERIOD 1873 TO 1968

the anomalous circulation in winter associated with dry winters over England and Wales. In this connection dry winters were those in the lowest tercile of rainfall in the 90-year period from December 1873 to February 1963, i.e. those with general rainfall over England and Wales less than or equal to 8·5 inches (216 mm) or 87 per cent of the 90-year average. The most striking feature of Figure 2(a) is the large area of above average pressure over the

Atlantic north of 40°N and most of Europe, with a centre near Ireland; a weaker but significant area of below average pressure is situated near Novaja Zemlja in the Russian Arctic. Wet winters, i.e. those with general rainfall greater than or equal to 10·9 inches (267 mm) or 111 per cent of the 90-year average, are typically associated with the mean pressure anomaly pattern shown in Figure 2(b), which is noteworthy for the large area of below average pressure centred near Ireland. Reversing the signs of the anomalies in Figure 2(a) gives a pattern quite like that in Figure 2(b). The mean pressure anomaly pattern associated with the middle tercile of rainfall (i.e. average rainfall) is featureless and is not shown.

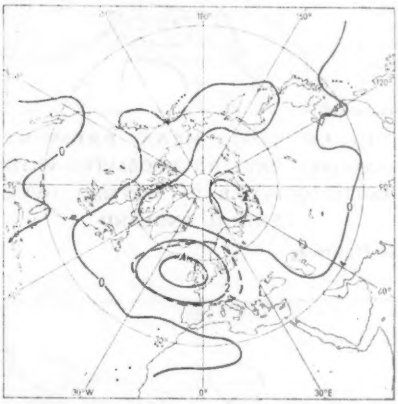

FIGURE 2(a)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH DRY (TERCILE 1) WINTERS OVER ENGLAND AND WALES

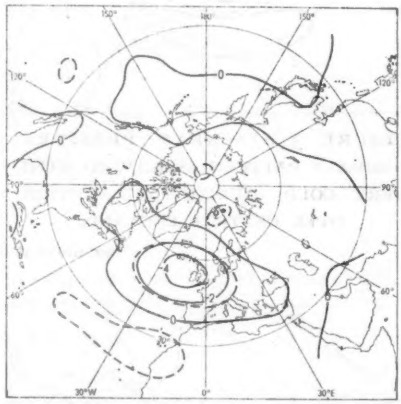

FIGURE 2(b)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH WET (TERCILE 3) WINTERS OVER ENGLAND AND WALES

Pressure anomalies (2-mb intervals) from 1873–1968 average. Broken lines enclose areas where anomalies are significantly different from zero at the 5 per cent level according to *t*-test.

The mean pressure anomaly map associated with very cold winters, as specified by central England mean winter temperatures (T_m) less than or equal to 2·9°C, is shown in Figure 3(a). For this purpose the central England temperatures of Manley[6] in quintile form derived from the same 90-year period as for rainfall have been employed. Figure 3(a) shows a powerful blocking pattern in the Atlantic sector and a weaker blocking pattern in the Pacific sector. The strong east to north-east anomaly of flow over the British Isles is particularly worthy of note.

Three other mean pressure anomaly maps are presented in Figures 3(b), (c) and (d), which are respectively based on groups of winters classified as quintile 2 ($2{\cdot}9 < T_m \leqslant 3{\cdot}9$°C), quintile 4 ($4{\cdot}4 < T_m \leqslant 5{\cdot}1$°C) and quintile 5 ($T_m > 5{\cdot}1$°C). These diagrams speak for themselves, but it is worth mentioning that Figure 3(d) is quite like Figure 3(a) with the signs of the anomaly patterns reversed. Particularly noteworthy in Figure 3(d) is the strong south-westerly anomaly of flow over the British Isles. The composite pattern associated with quintile 3 winters ($3{\cdot}9 < T_m \leqslant 4{\cdot}4$°C) is not shown; it is weaker than but rather like Figure 3(c), except that the North Atlantic negative anomaly centre is in the Denmark Strait.

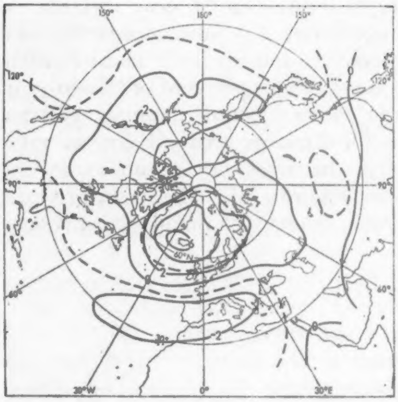

FIGURE 3(a)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH VERY COLD (QUINTILE 1) WINTERS OVER CENTRAL ENGLAND

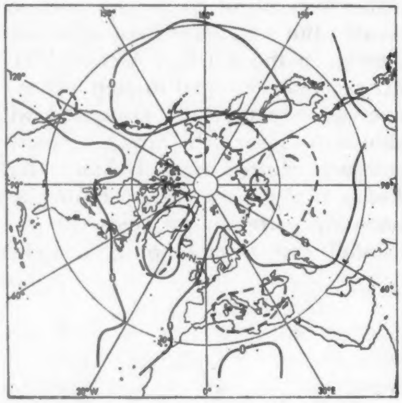

FIGURE 3(b)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH COLD (QUINTILE 2) WINTERS OVER CENTRAL ENGLAND

See notes at foot of Figure 2.

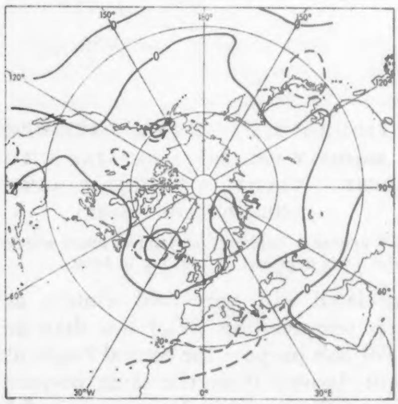

FIGURE 3(c)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH MILD (QUINTILE 4) WINTERS OVER CENTRAL ENGLAND

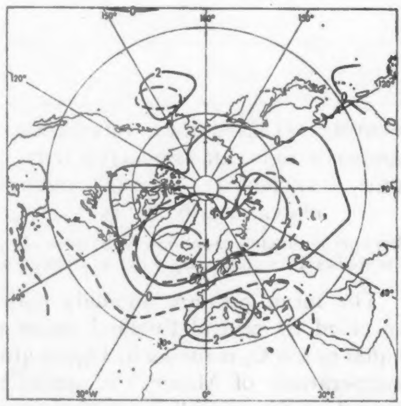

FIGURE 3(d)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH VERY MILD (QUINTILE 5) WINTERS OVER CENTRAL ENGLAND

See notes at foot of Figure 2.

Figures 2 and 3 clearly show that large-scale anomaly patterns typically occur over the Atlantic–European sector and these generally dominate the hemisphere whenever the winter temperature or rainfall over England and Wales is appreciably different from average.

Procedure. The procedure was quite simple. Five groups of winters were selected according to their mean winter temperature in quintile form in central England. In each class the mean pressure anomaly maps in

September, October and November preceding the winters in question were computed. Areas where the mean monthly pressure anomaly was significantly above or below zero were picked out by application of the *t*-test. An example is given in Figure 4 which is the composite mean pressure anomaly map in

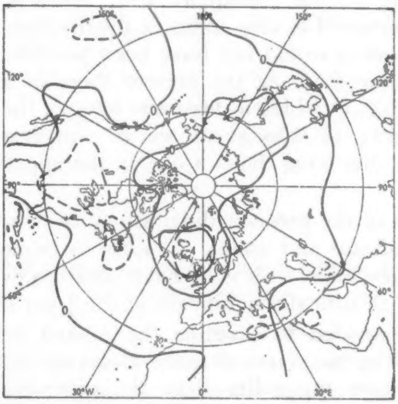

FIGURE 4—MEAN PRESSURE ANOMALY PATTERN IN OCTOBER PRECEDING COLD (QUINTILE 2) WINTERS OVER CENTRAL ENGLAND
See notes at foot of Figure 2.

October preceding cold (quintile 2 or T_2) winters (broken lines enclose areas significant at 5 per cent level). It appears from this figure that below average pressure off north-west Scotland and above average pressure from Newfoundland to the central U.S.A. typically occur before T_2 winters; in a few other small areas in low latitudes, significance is also indicated but these are rather doubtful in view of uncertainties in the basic data. The fact that mean pressure is below average near Scotland in Octobers preceding T_2 winters does not, of course, imply that Octobers in which the mean pressure near Scotland is below average are necessarily followed by T_2 winters. However, composite maps such as Figure 4 suggest that certain areas might well be key areas as regards circulation in helping to determine the type of winter to follow. The next step was to take the pressure anomaly at one (occasionally more than one) grid point within the significant area for each October since 1873 and to relate these values to the quintiles of the following winter. In many cases it seemed probable that an anomalous pressure gradient (e.g. an abnormally strong or weak westerly flow) might be more relevant than the pressure in a particular area; in such cases the differences between the anomalies at two points were computed for each month. In some cases a point was used where the pressure anomaly was not statistically significant but this was generally in order to obtain differences between this point and another point where the pressure anomaly was significant. The broad relationship between pressure anomaly data and subsequent winter temperature was readily seen by forming 5 × 5 contingency tables between the two quantities in quintiles. The chi-square value may, of course, be computed for such tables but the normal test of significance cannot strictly be applied

owing to uncertainty concerning the number of degrees of freedom since the data have been pre-selected. In such cases, 'apparently significant at the 5 per cent level' means that the table would have been significant if the data had not been specially selected. However, it was not found satisfactory merely to accept contingency tables which were apparently statistically significant according to the chi-square test. In a few cases, apparently significant tables contained a very complex distribution of frequencies in the cells and in such cases it would not have been possible to derive any usable rule for predictive purposes. At the present stage in long-range forecasting only contingency tables in which at least one wing of the pressure distribution shows a bias in terms of subsequent winter temperature can be used in prediction — if the other wing shows a bias in the opposite sense so much the better.

When both wings of the pressure distribution show a bias the contingency table is usually significant and useful. In some cases one wing might have a potentially useful association with winter temperature even though the whole 5×5 table was not statistically significant at the 5 per cent level.

It was therefore decided to examine the ranked pressure data in more detail. It was clear by inspection that there was often a more natural point in the ranked pressure anomalies than the quintile boundary for useful classification when the object was to associate a class of pressure anomaly data with a strongly biased distribution of quintiles of winter temperature. For this purpose objective criteria were adopted in selecting the classification boundary. These criteria are :

(a) The class must contain at least 15 years.

(b) If both ends of the pressure anomaly distribution appear to have an association with winter temperature then the Sutcliffe score* *(SS)* for each class must equal at least 1·2.

(c) If only one end of the pressure anomaly distribution appears to have an association with winter temperature then $SS \geqslant 1{\cdot}4$.

(d) For practical purposes the pressure class was taken so that the critical pressure anomaly boundary was a whole number (e.g. pressure anomaly $> 3{\cdot}0$ mb) provided also that (a) and (b) or (c) were satisfied.

The criteria (a) to (d) are arbitrary but objective. The so-called Sutcliffe score has been in use in the Meteorological Office for many years. Forecasts with mean $SS \geqslant 1{\cdot}2$ are generally regarded as satisfactory and those with $SS \geqslant 2{\cdot}2$ as very good. For convenience the scoring tables for temperature and rainfall are reproduced in Table I.

In the search for circulation predictions of winter rainfall (i.e. rainfall plus snowfall) the same general procedure was adopted as for temperature. In the rainfall case the pressure anomaly pattern before the three groups classified by terciles of rainfall and before the driest 10 per cent and the wettest 10 per cent of winters were investigated.

Unless otherwise stated the criteria (a) to (d) were adopted in selecting the predictors of winter temperature and rainfall which are discussed in the following sections. Occasionally the positions where pressure anomaly predictors were taken were rather near each other and clearly measured the

* Professor R. C. Sutcliffe originally put forward this simple scoring system; an example of its use is given by Freeman.[8]

TABLE I—SUTCLIFFE SCORES (*SS*) FOR TEMPERATURE FORECASTS IN QUINTILES AND RAINFALL FORECASTS IN TERCILES

(a) Temperature (quintiles)

	Actual				
Forecast	1	2	3	4	5
1	4	2	0	−2	−4
2	1	4	1	−2	−4
3	−3	1	4	−1	−3
4	−4	−2	1	4	1
5	−4	−2	0	2	4

(b) Rainfall (terciles)

	Actual		
Forecast	1	2	3
1	4	0	−4
2	−2	4	−2
3	−4	0	4

same type of circulation feature (e.g. pressure anomaly at 50°N 20°W and at 50°N 10°W); in such cases one was selected on the basis of its overall significance.

Forecasting winter rainfall. The analysed data indicate clearly that anomalous atmospheric circulation generally appears to be more important in September and October than in November in determining the winter rainfall over England and Wales. Predictions based on anomalous features of the circulation in each month of autumn are summarized in Table II. In this table positions are given in abbreviated form, e.g. 55 10 is 55°N 10°W and 55 10E is 55°N 10°E.

The positions at which the PA, or PA differences, are important in September are shown in Figure 5. Anomalously high or low pressure in

TABLE II—PRESSURE ANOMALIES OR PRESSURE ANOMALY DIFFERENCES FOR KEY AREAS IN SEPTEMBER, OCTOBER AND NOVEMBER, RELATED TO WINTER RAINFALL IN ENGLAND AND WALES

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Rainfall (terciles)		
				1	2	3
(a) September		*millibars*				
1	PA(55 10E)	1014·4	<−3	1	5	12
2	PA(55 10E)	1014·4	> 3	11	7	2
3	PA(35 40)−PA(55 10E)	1021·5−1014·4	<−2	14	12	2
4	PA(35 40)−PA(55 10E)	1021·5−1014·4	> 3	1	4	12
5	PA(80 100E)−PA(55 10E)	1012·0−1014·4	<−1	18	16	6
6	PA(80 100E)−PA(55 10E)	1012·0−1014·4	> 6	1	2	12
7	PA(85 180)−PA(50 180)	1015·9−1011·2	<−3	8	6	1
8	PA(85 180)−PA(50 180)	1015·9−1011·2	> 5	3	3	12
(b) October						
9	PA(80 100E)	1011·5	<−5	8	8	2
10	PA(80 100E)	1011·5	> 3	4	9	15
11	PA(80 100E)−PA(50 140)	1011·5−1010·7	< 0	20	14	7
12	PA(80 100E)−PA(50 140)	1011·5−1010·7	> 3	7	10	17
13	PA(25 120)−PA(45 160)	1014·8−1012·3	> 4	2	4	11
(c) November						
14	PA(60 50)	1002·5	<−4	11	5	3
15	PA(45 20E)	1018·1	> 3	10	4	2
16	PA(65 10E)−PA(60 60)	1007·6−1006·0	> 6	9	7	1

Normal monthly pressure or pressure difference is based on the period 1873 to 1968.
Note : Tercile boundaries are : $R_1 \leqslant 216$ mm; $216 < R_2 \leqslant 276$ mm; $R_3 > 277$ mm.

the polar region with the opposite type of anomaly in the Aleutians and also near Denmark are clearly of importance in September. Anomalous flow (S/SE or NW/N) in the Atlantic, measured objectively by the PA difference

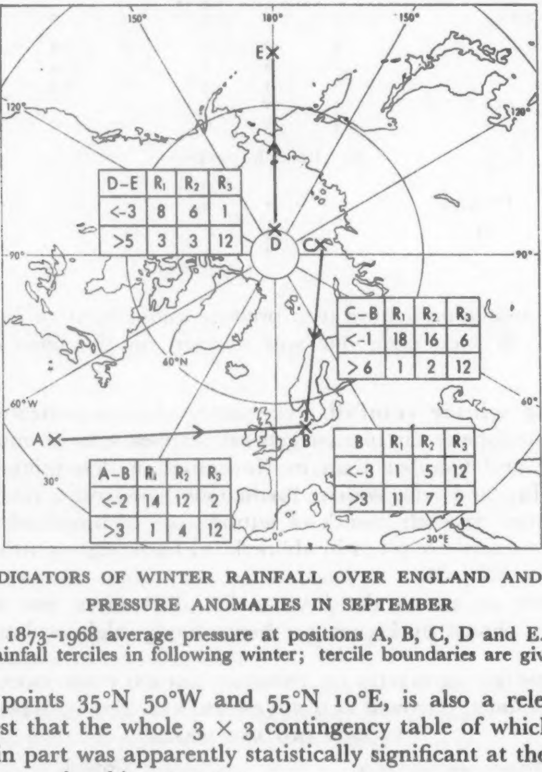

FIGURE 5—INDICATORS OF WINTER RAINFALL OVER ENGLAND AND WALES FROM PRESSURE ANOMALIES IN SEPTEMBER

Anomalies from 1873–1968 average pressure at positions A, B, C, D and E. Boxes contain frequencies of rainfall terciles in following winter; tercile boundaries are given in Table II.

between the points 35°N 50°W and 55°N 10°E, is also a relevant feature. It is of interest that the whole 3 × 3 contingency table of which rules 3 and 4 are the main part was apparently statistically significant at the 0·1 per cent level according to the chi-square test.

Table II also indicates that the October circulation contains features of importance. However, the November circulation appears to be useful for predicting dry winters, although no worthwhile rules (based on criteria (a) to (d) of the previous section) have come to light for predicting wet winters.

Application of the rules of Table II to a particular case usually means that some are satisfied but their predictions may not agree. It might be thought that more weight should be given to a rule based on circulation in November (i.e. nearer to the winter) than to one based on circulation in September, but the facts of the past century do not agree with this supposition. Moreover, it is far from clear that anomalous circulation features in the Atlantic sector should be given more (or less) weight than anomalous circulation features in, say, the polar basin. Weights could be given to the different rules on the basis of frequency of occurrence of individual years in each rule, or according to the total number of years in the frequency distribution, or according to the mean *SS*, or to some combination of all these. In the end it was decided to stick to a quite simple discriminant procedure which will be made clear in the tables which follow.

It is clear from Table III that the September predictors $N_d - N_w \geqslant 2$ and $N_d - N_w \leqslant -1$ give, respectively, very strong indications of dry (*SS* = 2·6) and wet (*SS* = 2·5) winters to follow. Indeed in these cases only 3 out of 45 years were two terciles different from expectations. However, prediction of average rainfall is less satisfactory (*SS* = 0·8). Moreover, 18 years were not considered in Table III since none of the primary predictions of Table II applied.

TABLE III—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN SEPTEMBER, OCTOBER AND NOVEMBER OVER THE NORTHERN HEMISPHERE AND WINTER RAINFALL OVER ENGLAND AND WALES

Month	Predictor	Winter rainfall (terciles) 1	2	3	Totals	*SS*
(a) September	$N_d - N_w$					
	$\geqslant 2$	14	7	0	21	2·6
	0 or 1	10	16	8	34	0·8
	$\leqslant -1$	3	3	18	24	2·5
(b) October	$N_d - N_w$					
	$\geqslant 1$	19	14	3	36	1·7
	0 or -1	6	8	9	23	—
	$\leqslant -2$	3	7	14	24	1·8
(c) November	N_d					
	0	15	19	26	60	0·7
	1	11	9	5	25	0·9
	$\geqslant 2$	8	4	0	12	2·6

N_d and N_w are the number of individual monthly rules (see Table II) which indicate dry (tercile 1) and wet (tercile 3) winters respectively. *SS*=Sutcliffe score. Tercile boundaries are given in Table II.

As regards predictions based on October circulation, $N_d - N_w \geqslant 1$ and $N_d - N_w \leqslant -2$ are clearly useful predictors; in this case only 6 out of 60 years differed from expectation by two terciles. However, some 12 years were not incorporated into Table III since the individual predictors of Table II were not applicable.

In November the criterion $N_d \geqslant 2$ apparently gives a useful prediction in a small minority of years (12 only). Moreover, no November predictors were available for wet winters.

Table III gives some useful predictions, especially in September and October, but there are evidently a fairly large number of occasions when no satisfactory rule based on any single month is applicable. The next step is to combine the separate monthly indications. This is done for September and October and also for the three autumn months in Table IV.

Table IV (a) shows that the specified anomalous features of the circulation in September and October are closely associated with the raininess of the following winter. The 3 × 3 contingency table contains nearly 95 per cent of the data. In rows 1 and 3 there are only five cases which differ by 2 terciles from the expected value of tercile 1 or 3 respectively. Even stronger indications are given if more stringent criteria are employed; these are shown in brackets.

Table IV (b) summarizes the results using objective predictors based on the three autumn months. In general the addition of November does not add much, but some gain is obtained in, for instance, applying the rule given in the bottom row. Once again, very strong indications are in evidence on those occasions when the stringent criteria shown in brackets are laid down.

TABLE IV—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN (a) SEPTEMBER AND OCTOBER AND IN (b) SEPTEMBER, OCTOBER AND NOVEMBER OVER THE NORTHERN HEMISPHERE AND WINTER RAINFALL OVER ENGLAND AND WALES

Period	Predictor $N_d - N_w$	Winter rainfall (terciles) 1	2	3	Totals	*SS*
	≥ 1 (≥ 3)	26 (11)	15 (6)	3 (0)	44	2·0
(a) September	0 or −1	4	12	5	21	1·4
and October	≤ -2 (≤ -4)	2 (0)	5 (0)	20 (9)	27	2·6
(b) September,	≥ 1 (≥ 3)	28 (15)	19 (9)	3 (0)	50	2·0
October and	0 or −1	5	9	6	20	0·7
November	≤ -2	0	4	19	23	3·3

N_d and N_w are the number of individual monthly rules (see Table II) which indicate dry (tercile 1) and wet (tercile 3) winters respectively. *SS* = Sutcliffe score. Tercile boundaries are given in Table II.

Note : For a predictor value given in brackets the tercile distribution is shown in brackets.

The stability of relationships such as those shown in Table IV can be tested to some extent by breaking down the whole period and examining the associations in the separate periods. The associations between $N_d - N_w$ and winter rainfall in (a) the so-called 'westerly epoch' (normally taken as 1896 to 1939) and (b) the 'blocked epoch' (taken as before 1896 and after 1939) for the autumn are summarized in Table V.

TABLE V—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN SEPTEMBER, OCTOBER AND NOVEMBER OVER THE NORTHERN HEMISPHERE AND WINTER RAINFALL OVER ENGLAND AND WALES IN THE 'WESTERLY' EPOCH (1896–1939) AND THE 'BLOCKED' EPOCH (1873–95 AND 1940–69)

Epoch	Predictor $N_d - N_w$	Winter rainfall (terciles) 1	2	3
(a) Westerly	≥ 1	10	6	1
	0 or − 1	2	5	4
	≤ -2	0	2	13
(b) Blocked	≥ 1	18	13	2
	0 or − 1	3	4	2
	≤ -2	0	2	6

N_d and N_w are the number of individual monthly rules (see Table II) which indicate dry (tercile 1) and wet (tercile 3) winters respectively. Tercile boundaries are given in Table II.

It is clear from Table V that the same types of associations between $N_d - N_w$ and winter rainfall hold in both the westerly and the blocked epochs. The different frequencies of cases with $N_d - N_w \geq 1$ and ≤ -2 in the two epochs are simply due to the climatological tendency for blocking to be associated with dry rather than with wet winters and, of course, occurrences of blocking were less frequent in group (a) and more frequent in group (b).

The prediction of dry or wet winters does not imply that each month of the winter will be dry or wet. Indeed a feature of the climatology of dry or wet winters is that only a small minority of such winters have all their months either dry or wet. In the case of rules contained in Table IV (b) a few facts are worth noting. For $N_d - N_w \geq 1$, (1) the strongest bias to dry is in January (24 R_1, 21 R_2 and 5 R_3) and the weakest bias in February; (2) over 90 per cent of winters have two or more dry or average months; (3) if December is wet, then January is very likely to be dry and February has a somewhat weaker tendency to be average. For $N_d - N_w \leq -2$, (1) the

strongest bias to wet is in December, the next strongest is in January whereas February is more likely to have average rainfall; (2) 100 per cent of winters have two or more wet or average months. For $N_d - N_w = 0$ or -1, there is little bias in each month except for a tendency for average rainfall in December.

Forecasting winter temperature. Following the same general procedure various predictors in each autumn month were selected as shown in Table VI with a view to predicting winter mean temperature in central England.

TABLE VI—PRESSURE ANOMALIES OR PRESSURE ANOMALY DIFFERENCES FOR KEY AREAS IN SEPTEMBER, OCTOBER AND NOVEMBER RELATED TO WINTER MEAN TEMPERATURE IN CENTRAL ENGLAND

Rule No.	Pressure anomaly (PA) or difference	Normal	Critical anomaly	Temperature (quintiles)				
		millibars		1	2	3	4	5
(a) September								
1	PA(55 20)	1011·0	<-3	5	11	1	0	2
2	PA(35 20) − PA(55 20)	1020·4 − 1011·0	>3	4	13	2	0	2
3	PA(45 60E) − PA(55 20)	1016·1 − 1011·0	>4	4	11	1	0	2
4	PA(55 10) − PA(60 70)	1012·9 − 1009·1	<-4	5	10	3	0	4
(b) October								
5	PA(65 20)	1004·9	<-5	2	10	4	2	1
6	PA(40 90)	1018·3	>1	3	14	8	1	4
7	PA(60 10) − PA(40 10)	1007·2 − 1017·3	<-6	4	11	3	3	1
8	PA(55 00)	1012·3	<-3	6	12	6	4	1
9	PA(80 160E)	1015·8	>4	1	4	5	3	10
10	PA(80 160E) − PA(60 40)	1015·8 − 1004·7	<-6	9	5	3	3	1
11	PA(80 160E) − PA(60 40)	1015·8 − 1004·7	>6	0	4	5	2	8
12	PA(55 00) − PA(60 40)	1012·3 − 1004·7	<-7	5	7	7	2	1
13	PA(80 80E)	1010·2	<-6	6	5	0	4	0
14	PA(80 80E)	1010·2	>5	1	2	4	2	8
15	PA(65 20) − PA(80 80E)	1004·9 − 1010·2	>8	9	2	1	4	0
(c) November								
16	PA(60 50) − PA(65 10E)	1002·5 − 1007·6	>7	3	9	3	4	0
17	PA(55 10)	1009·7	>-6	2	4	1	10	1

Normal monthly pressure or pressure difference based on period 1873 to 1968.
Note: Quintile boundaries, based on period 1874 to 1963, are as follows: $T_1 < 3{\cdot}0^\circ$C; $3{\cdot}0 \leqslant T_2 < 4{\cdot}0$; $4{\cdot}0 < T_3 < 4{\cdot}5$; $4{\cdot}5 \leqslant T_4 < 5{\cdot}2$; $T_5 > 5{\cdot}2^\circ$C.

It is evident from Table VI that more predictors occur in October than in the other two months. This is in accord with a suggestion of Hay[1] that October is the most critical autumn month in determining winter temperature over central England. An attempt is made to combine the predictors from each month as indicated in Table VII.

Table VII summarizes the rules which have been developed on the basis of all the indications contained in Table VI. Using only September data, one useful rule is obtained for predicting T_2 winters but it can be invoked on less than 25 per cent of the years. Using only October data, predictions of T_5 and T_1 or T_2 can be made on about 60 per cent of occasions, and the accuracy of the forecasts of very mild winters is likely to be very high. Using only November data, worthwhile predictions of T_4 and T_2 winters can be made on 34 per cent of occasions. However, the overall rule derived from the September, October and November circulation data (i.e. (d)) appears likely to be usable on nearly 80 per cent of occasions, but with a high degree of accuracy on some 60 per cent of occasions when the conditions in rows 1, 4 and 5 are satisfied. In these 60 cases there are only 5 with negative values

TABLE VII—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN SEPTEMBER, OCTOBER AND NOVEMBER OVER THE NORTHERN HEMISPHERE AND MEAN WINTER TEMPERATURE IN CENTRAL ENGLAND

Period	Predictors	Winter temperature (quintiles) 1	2	3	4	5	Totals	*SS*
(a) September	$N_c \geq 2$	6	13	2	0	2	23	2·2
(b) October	$N_c - N_m \geq 2$	13	16	5	8	1	43	1·4
	$N_c - N_m = 0$ or 1	7	7	12	6	5	37	—
	$N_c - N_m \leq -1$	0	0	2	4	11	17	3·0
(c) November	$N_c - N_m > 0$	3	8	3	3	0	17	1·9
	$N_c - N_m = 0$ or 1	15	12	15	6	16	64	—
	$N_c - N_m < 0$	2	3	1	9	1	16	1·5
(d) September,	$N_c - N_m \geq 3$	10	17	4	2	2	35	2·0
October	$N_c - N_m = 2$	4	5	5	4	1	19	0·9
and	$N_c - N_m = 0$ or 1	5	1	7	3	2	18	—
November	$N_c = N_m = 0$	1	0	2	3	1	7	1·5
	$N_c - N_m \leq -1$	0	0	1	6	11	18	3·1

N_c and N_m are the number of individual monthly rules (see Table VI) which indicate cold (T_1 or T_2) and mild (T_4 or T_5) winters respectively. *SS* = Sutcliffe score.

of the Sutcliffe score (i.e. seriously in error). It is less satisfactory that when $N_c - N_m \geqslant 3$ the prediction is cold (T_2) rather than very cold (T_1).

The value of the rule (d) in Table VII in the 'blocked' and 'westerly' epochs was next examined. The results are shown in Table VIII.

TABLE VIII—LAG ASSOCIATIONS BETWEEN VARIOUS COMBINATIONS OF RULES BASED ON MONTHLY PRESSURE ANOMALIES IN SEPTEMBER, OCTOBER AND NOVEMBER OVER THE NORTHERN HEMISPHERE AND WINTER MEAN TEMPERATURE IN CENTRAL ENGLAND IN THE 'WESTERLY' EPOCH (1896–1939) AND THE 'BLOCKED' EPOCH (1873–95 AND 1940–69)

Epoch	Predictor	Winter mean temperature (quintiles) 1	2	3	4	5
(a) Westerly	$N_c - N_m \geq 3$	0	8	3	1	2
	$N_c - N_m \leq -1$	0	0	1	2	9
(b) Blocked	$N_c - N_m \geq 3$	10	9	1	1	0
	$N_c - N_m \leq -1$	0	0	0	4	2

N_c and N_m are the number of individual monthly rules which indicate cold (T_1 or T_2) and mild (T_4 or T_5) winters respectively.

Substantially the same types of predictions apply in both epochs. Not unexpectedly there are more cold winters and fewer mild ones in the 'blocked' epoch compared with the 'westerly' epoch. Moreover, in the 'blocked' epoch, when $N_c - N_m \geqslant 3$ the following winters are just as likely to be quintile 1 as quintile 2. In the 'westerly' epoch, when $N_c - N_m \geqslant 3$, no quintile 1 was observed.

As regards the individual winter months the prediction of the seasonal mean temperature as cold (T_1 or T_2) or mild (T_4 or T_5) does not signify that each month will have the same quintile classification. There are some interesting features connected with the overall autumn rule (d) of Table VII. For $N_c - N_m \geqslant 3$, (1) some 60 per cent of winters have at least two cold (T_1 or T_2) months; (2) if December is cold (T_1 or T_2), then February is also quite likely to be cold (8 T_1, 3 T_2, 4 T_3, 2 T_4 and 3 T_5) but January has little bias to cold; (3) if December is mild (T_4 or T_5) then the distribution of quintile frequencies in the other months is random. For $N_c - N_m \leqslant -1$,

(1) no very cold (T_1) month occurs and only two T_2 Decembers occur; (2) all Januarys and Februarys have near or above average temperatures $(T_3, T_4 \text{ or } T_5)$.

So far in this section anomalous circulation features in autumn over the northern hemisphere have been employed in deriving objective rules for predicting winter temperature. Several years ago, following the derivation of the *PSCM* indices of Murray and Lewis,[9] the writer noted that progressive cyclonic autumns were related to cold winters in central England and this rule was illustrated in an article by Murray.[1] It is worth mentioning a few elaborations of the progressive cyclonic autumn rule in predicting cold winters, and these are summarized in Table IX.

TABLE IX—VARIOUS ASSOCIATIONS BETWEEN CIRCULATION NEAR THE BRITISH ISLES AS MEASURED BY *PSCM* INDICES IN AUTUMN AND MEAN TEMPERATURE IN CENTRAL ENGLAND IN WINTER

Rule No.	Predictors	Winter temperature (quintiles) 1	2	3	4	5	Totals	*SS*
1	$P_{45}\ C_{45}$ autumn	3	13	5	3	1	25	2·0
2	$S_{12}\ C_{45}$ autumn	5	6	5	1	0	17	1·8
3	$P_{45}\ C_{45}$ and/or $S_{12}\ C_{45}$ autumn (counting common years once)	6	15	6	4	1	32	1·9
4	$P_{45}\ C_{45}$ in autumn and also in at least one of September, October or mid-September to mid-October	3	11	4	1	0	19	2·5

$P_{45}\ C_{45}$ signifies quintiles 4 or 5 in *P* (progressive) index and in *C* (cyclonic) index; similarly for $S_{12}\ C_{45}$ (northerly cyclonic). *SS* = Sutcliffe score.

On a limited number of occasions these *PSCM* values in Table IX are applicable and useful. Number 4 in particular shows a very close connection between the specified pre-conditions and quintile 2 winters. The *PSCM* indications add a little on a few occasions to the broader-based rules contained in Table VII. There are no strong *PSCM* rules for predicting mild winters.

Before ending this section it must be said that the prediction of severe winters is not satisfactory, and much more work needs to be done on this particular problem.

Concluding remarks. Experience and judgement have gone into certain aspects of this work, particularly in deciding the levels at which possible criteria should be accepted or rejected, but once the basic predictors in Tables II and VI were accepted the rules derived are quite objective and readily used in practice. No doubt better rules may subsequently be derived, especially by bringing in other physically based predictors and by elaborating the statistical treatment, e.g. by the use of discriminant analysis. However, the present rules set a standard which more sophisticated procedures in the future must exceed in accuracy if they are to be worth while in practical forecasting.

It is also worth stressing that there are inevitably some occasions when none of the rules can be applied. In such cases other methods must be adopted or no forecast should be issued. It should be noted in addition that even the most strongly based rule may fail on a few occasions. Prediction on all time-scales is a question of probability rather than certainty. Even the most sophisticated procedures of the distant future will not always predict correctly on the seasonal or any other time-scale.

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551.510.53:551.557.5

A NOTE ON EQUATORIAL STRATOSPHERIC WINDS*

By R. A. EBDON

Summary. Stratospheric (30-mb) wind data are used to illustrate how the monthly mean patterns vary during selected Januarys and Julys when the winds in the equatorial stratosphere are established easterlies or westerlies. Charts are presented for two selected days — one during an easterly and the other during a westerly régime in the equatorial stratosphere. On both the monthly and the daily time-scales the wind régimes associated with the quasi-biennial oscillation appear to be such that easterly or westerly winds can encircle the earth in the equatorial stratosphere.

Introduction. Since 1960 when the quasi-biennial oscillation (QBO) in the zonal component of equatorial stratospheric winds was first reported, many papers have been written which describe its main characteristics. It is usually stated that the alternating easterly and westerly currents encircle the earth in the equatorial zone and that the effects of the oscillation decrease with increasing latitude. Very often questions are asked regarding the latitudinal extent of the actual easterly and westerly régimes and whether or not the easterlies and westerlies are continuous around the equatorial zone. Lack of an adequate network of stratospheric wind observations makes it difficult to answer these questions with complete confidence, but in an attempt to do so, the available 30-mb (24 km) data have been used to examine the wind régimes in the northern and southern hemispheres for particular months, and in the equatorial zone for particular days, when the phase of the QBO

* This note is based on a paper presented at a symposium on 'Equatorial currents in atmospheres and oceans' held on 21 May 1971 and organized by the Royal Astronomical Society jointly with the Royal Meteorological Society and The Challenger Society.

was easterly or westerly. The choice of months to be examined was determined by the availability of data as well as by the phase of the QBO. Also, the investigation was restricted to the months of January and July which are representative of the established winter (westerly) and summer (easterly) wind régimes in middle and high latitudes.

The monthly mean zonal wind components at 50 mb (20·5 km) and 30 mb (24 km) for Canton Island (2° 46′S 171° 43′W) from May 1954 to August 1967 and for Gan (00° 41′S 73° 09′E) from September 1967 onwards are shown in Figure 1, and the months referred to later in the text are indicated for ease of reference. The QBO itself is very clearly defined in these curves

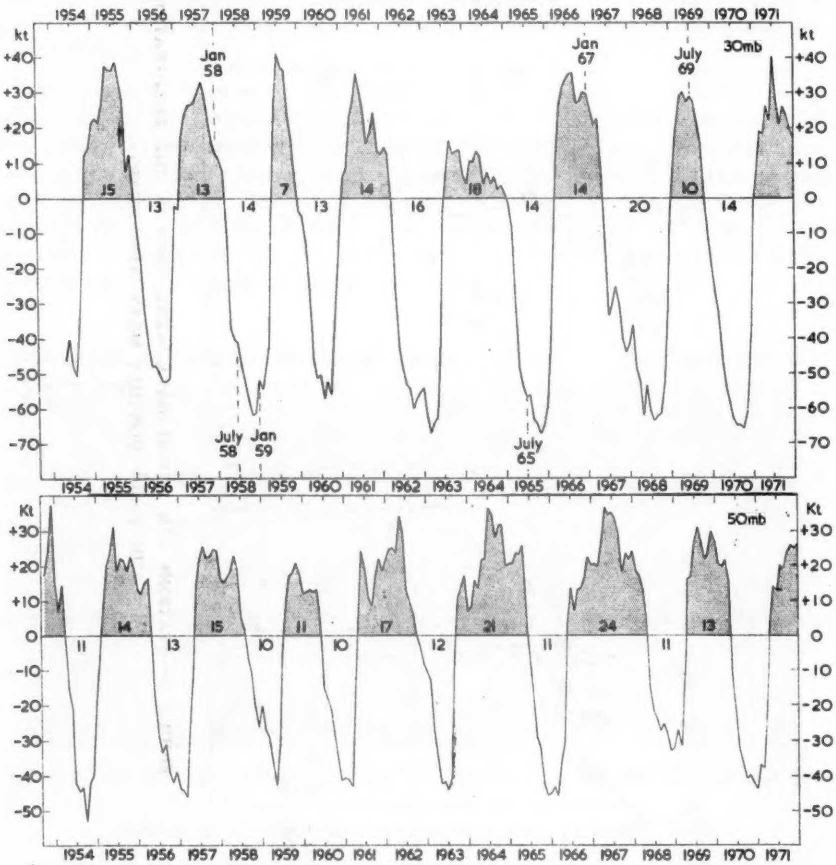

FIGURE 1—MONTHLY MEAN ZONAL WIND COMPONENTS AT 30 mb AND 50 mb FOR CANTON ISLAND, OCTOBER 1953 TO AUGUST 1957 AND FOR GAN, SEPTEMBER 1967 ONWARDS

Components towards the east are positive and stippled. Figures along the zero line indicate the duration, in months, of westerlies or of easterlies. Months mentioned in the text are annotated.

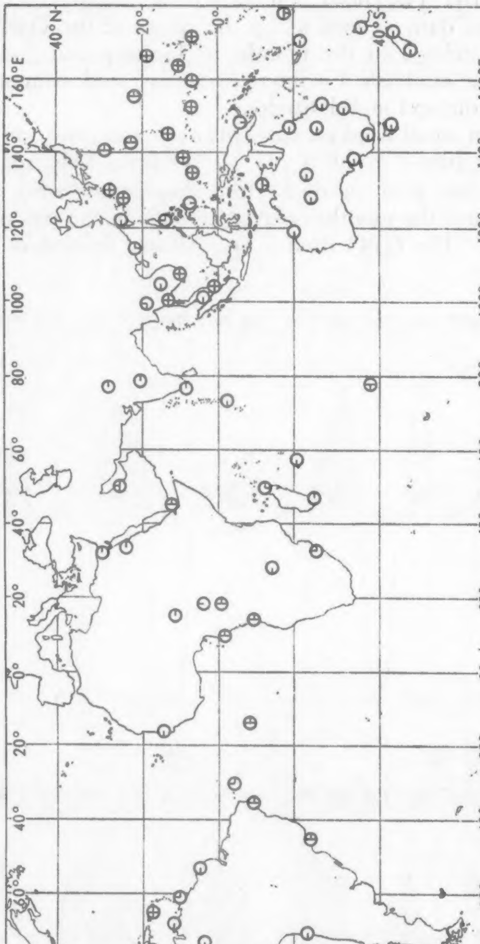

FIGURE 2—STATIONS FOR WHICH DATA WERE USED IN THE PREPARATION OF THE 30-mb MONTHLY MEAN WIND CHARTS

and its relative importance can be judged by the fact that a more detailed analysis has shown that it accounts for about 70 per cent of the total variance at 30 mb and 65 per cent at 50 mb, whilst the annual variation accounts for only 4 per cent and 6 per cent of the total variance at the same two levels.[1]

The stations for which monthly mean winds were used in constructing the charts are indicated in Figure 2. Only those stations between 30°N and 50°S are shown because north of 30°N there are many more reporting stations over some parts of the hemisphere and only those required to position the isopleths were used. The available data suggest that, in low latitudes, the predominantly easterly and westerly wind régimes — when they are established — are organized in definite latitude zones but clearly there are large areas over which observations are non-existent, and the analysis in these areas relies largely on what happens at comparable latitudes where observations are more adequate.

The easterly phase of the QBO. Figure 3 shows the monthly mean wind pattern for January 1959 (two months after an easterly maximum of the QBO). The strong (greater than 50 kt) easterlies are continuous in a belt extending from about 5°N to nearly 20°S. To the south of this, in the summer hemisphere, the winds are light easterly. To the north of the equator, in the winter hemisphere, the easterlies extend to 25°N or beyond — especially over the Pacific in the region of the Aleutian stratospheric high. Farther north the winds are generally westerly.

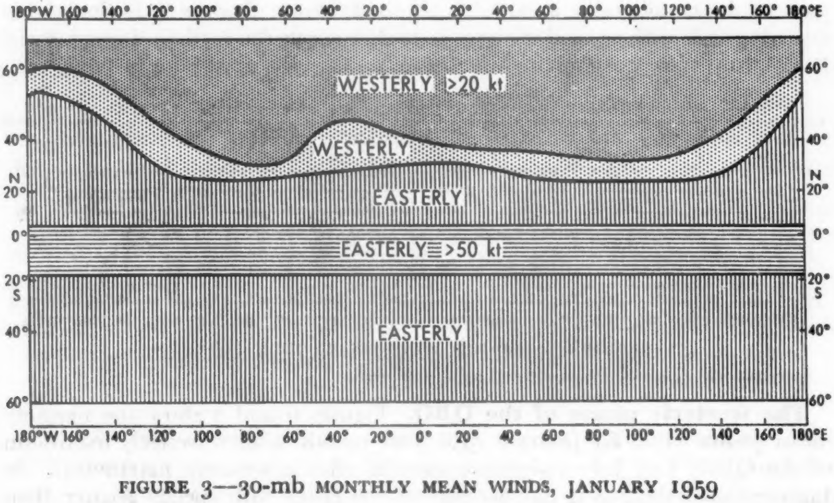

FIGURE 3—30-mb MONTHLY MEAN WINDS, JANUARY 1959

In July 1958 (four months before an easterly maximum of the QBO) the monthly mean winds show a belt of strong (greater than 50 kt) easterlies from near the equator to about 20°N (see Figure 4). To the north of this (in the summer hemisphere) the winds are light easterly. South of the equator (in the winter hemisphere) the easterlies extend to about 35°S and then change to the westerlies typical of winter.

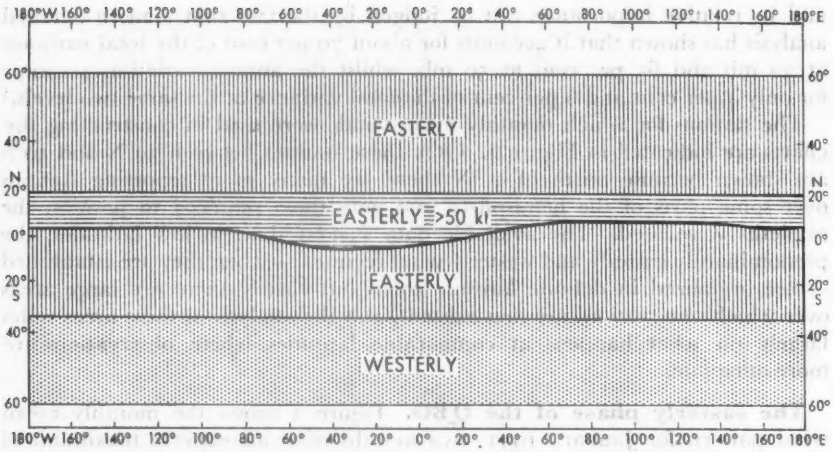

FIGURE 4—30-mb MONTHLY MEAN WINDS, JULY 1958

From these two diagrams it is clear that when the phase of the QBO is easterly and the easterlies are strong, there is a broad band of strong easterlies with its axis not at the equator but displaced into the summer hemisphere. There can be little doubt that these easterlies are continuous around the equator on the monthly mean chart.

The chart for an individual day, 29 July 1965 (Figure 5), shows that, in spite of the considerable areas with no observations, there is little doubt that easterly winds with a speed of about 50 kt do encircle the earth in the equatorial belt. (July 1965 was four months before an easterly maximum of the QBO.)

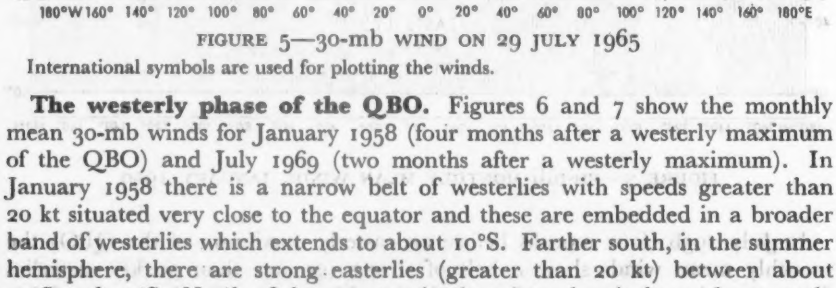

FIGURE 5—30-mb WIND ON 29 JULY 1965

International symbols are used for plotting the winds.

The westerly phase of the QBO. Figures 6 and 7 show the monthly mean 30-mb winds for January 1958 (four months after a westerly maximum of the QBO) and July 1969 (two months after a westerly maximum). In January 1958 there is a narrow belt of westerlies with speeds greater than 20 kt situated very close to the equator and these are embedded in a broader band of westerlies which extends to about 10°S. Farther south, in the summer hemisphere, there are strong easterlies (greater than 20 kt) between about 12°S and 37°S. North of the equator, in the winter hemisphere, the westerly component decreases and easterly winds appear over quite considerable areas. In higher latitudes the typical winter stratospheric westerlies are established.

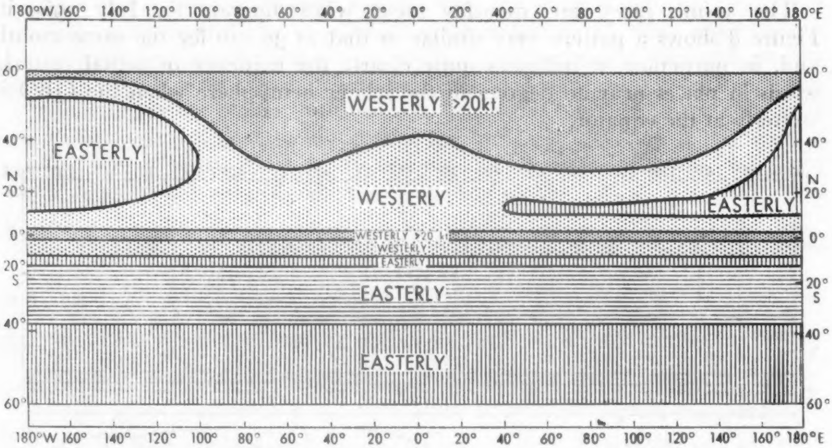

FIGURE 6—30-mb MONTHLY MEAN WINDS, JANUARY 1958

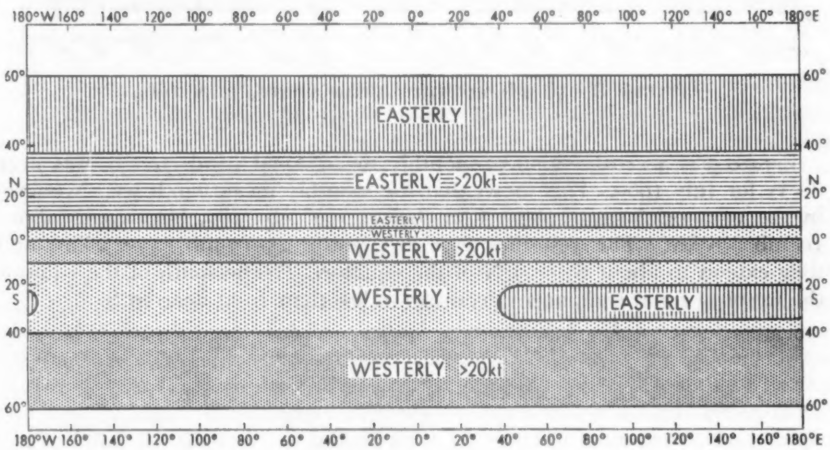

FIGURE 7—30-mb MONTHLY MEAN WINDS, JULY 1969

In July 1969 there is a narrow (about 10 degrees) band of westerly winds with speeds greater than 20 kt from the equator to 10°S. These westerlies extend to about 5°N, at which latitude a change-over to easterly takes place. Farther north, in the summer hemisphere, there are stronger easterlies between about 12°N and 37°N. In higher latitudes there are the light easterlies typical of summer. To the south of the equator, in the winter hemisphere, the westerly component decreases — with easterlies appearing in some areas between about 20°S and 35°S. South of this minimum westerly the zonal component increases again to the stronger westerly régime typical of the higher-latitude winter.

The 50-mb (20·5 km) monthly mean wind diagram for July 1969 in Figure 8 shows a pattern very similar to that at 30 mb for the same month and, in particular, it indicates quite clearly the existence of actual easterly winds in places near 20 degrees in the winter hemisphere when the QBO is westerly at the equator.

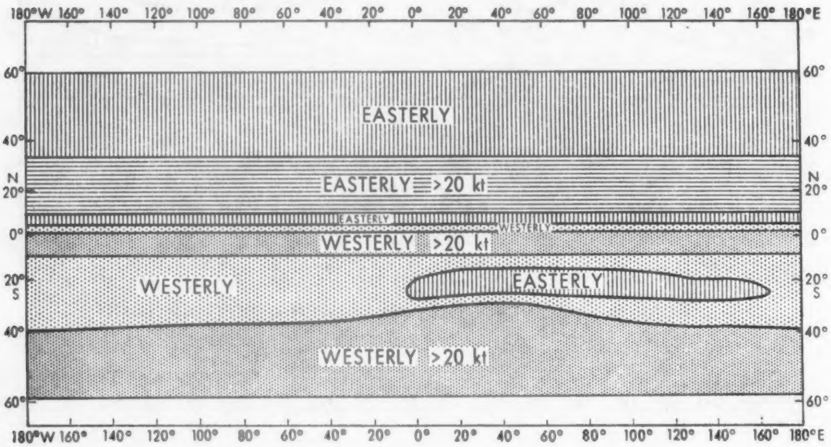

FIGURE 8—50-mb MONTHLY MEAN WINDS, JULY 1969

Figure 9 is a cross-section of monthly mean zonal wind components near 80°W for July 1969. This shows that the monthly mean winds were westerly in the equatorial stratosphere from below 100 mb (16·5 km) up to above 10 mb (30 km). The westerlies were strongest at 25–15 mb (25–27 km) and they extend to about 6° or 7°N of the equator. To the south of the equator the westerly zonal component decreases to less than 10 kt near 20°S.

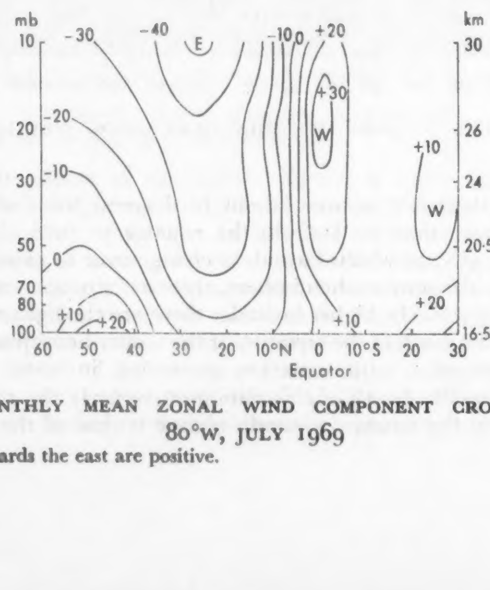

FIGURE 9—MONTHLY MEAN ZONAL WIND COMPONENT CROSS-SECTION NEAR 80°W, JULY 1969

Components towards the east are positive.

Figures 6, 7 and 8 certainly suggest that the belts of stronger westerlies are continuous around the equator on the monthly mean wind charts but it is of interest to know if these westerlies do, in fact, encircle the earth on any particular day. The 30-mb winds between 10°N and 10°S on 18 January 1967 are shown in Figure 10 and, in spite of the large areas for which no data exist, one is bound to say that it appears very much as if the wind is westerly about 30 kt all the way around the equator. (January 1967 was four months after a westerly maximum of the QBO.)

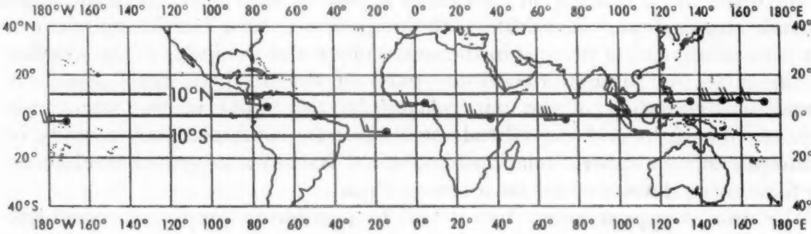

FIGURE 10—30-mb WINDS ON 18 JANUARY 1967
International symbols are used for plotting the winds.

Further discussion. The data presented in this note suggest that on both the monthly and the daily time-scales the wind régimes associated with the QBO are such that easterly or westerly winds can encircle the equator. Any general circulation model, if it is to describe winds in the equatorial stratosphere, must cater for quite rapid changes from westerly to easterly or vice versa in both the vertical and the horizontal (i.e. with increasing latitude) and also for the westerly and easterly régimes being continuous around the equator.

It is of interest to note that further evidence of the continuity of the low-latitude easterly and westerly régimes is provided by the balloon flights, at heights of 20–24 km, launched from Ascension Island (07° 58′S 14° 24′W) in connection with feasibility studies concerning the first Global Atmospheric Research Programme (GARP) global experiment.[2] One such flight was launched on 11 June 1970 and the balloon remained in the latitude band approximately 15°S to the equator whilst orbiting the earth six times during its 105-day flight. This flight took place during a strong easterly phase of the QBO. Another flight was launched from Ascension Island on 22 August 1969 and flew for 111 days during which time the QBO changed phase from westerly to easterly. This balloon remained in the latitude band 13°S–3°N and completed one and a half orbits in the westerly winds before reversing its direction of travel in the easterly circulation. These flights were launched at 8°S but, as is suggested in the progress report on the development of this work,[2] three launching sites are needed (one located close to the equator, one at 5°–10°N and one at 5°–10°S) in order to provide a more complete description of the behaviour of tropical stratospheric winds.

It is apparent that in preparing a descriptive note of this nature the lack of adequate stratospheric wind data imposes a severe restriction on the analysis which it is possible to undertake and also on the confidence which can be placed in the analysis. Although an effort was made to ensure that months and days were used which provided the maximum data coverage

there are considerable areas for which no observed winds were available. Nevertheless, it is felt that these diagrams do provide a little more descriptive material regarding the behaviour of the QBO and how it fits into the global circulation patterns. The charts presented here deal only with particular Januarys and Julys — it may well be that similar charts for other months over a longer period could provide much more useful information and materially add to an understanding of the role of the QBO. Such charts might provide synoptic evidence in support of the suggestion that the phase of the QBO has a bearing on the time of the spring wind reversal in the high-latitude stratosphere.[3] In addition, there appears to be a correlation between the time of this spring reversal in the stratosphere and the index of the weather of the following summer over some parts of the northern hemisphere. A better understanding of the part played by the QBO in the interaction between the high- and low-latitude stratospheres, combined with a study of stratospheric/tropospheric relationships, might lead to a suggested mechanism for forecasting developments for a season ahead.

The time is approaching when it will be possible to prepare stratospheric charts with more confidence in some low-latitude areas. The implementation of the World Weather Watch Global Observing System combined with the plans being made for the improvement in data coverage for the World Meteorological Organization's Atlantic Tropical Experiment of the Global Atmospheric Research Programme (GATE) will certainly result in a far more adequate network of radiosonde and radiowind stations in some tropical areas. In spite of this improved coverage over a wide area, there will still be regions of the tropics over which the network of stations reporting stratospheric winds will probably remain as it is at present and in these areas detailed analysis will remain difficult and uncertain.

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TEMPERATURE CORRECTIONS FOR THE SKUA ROCKETSONDE TEMPERATURE SENSOR

By B. D. MASON and J. ACRES

Summary. The temperature profile of the stratosphere and lower mesosphere is investigated by means of a parachute-borne tungsten-wire sensor carried to heights above 70 km by a SKUA rocket. The temperature recorded by the sensor is not the true air temperature because the sensor is subjected to various forms of heat transfer during its descent. This paper describes tests which have recently been conducted in a low-density wind-tunnel and a vacuum chamber to determine the corrections to be applied. The wind-tunnel tests were performed over a range of speeds corresponding to the normal fall-speed of the SKUA rocketsonde at pressures equivalent to heights between 35 km and 61 km whilst the vacuum-chamber experiments enabled the corrections for infra-red and solar radiation to be obtained. From the results presented it is concluded that for rocket soundings during the hours of darkness the only major correction to be applied is caused by dynamic heating.

Introduction. The temperature sensor used in the SKUA meteorological rocketsonde (Almond[1]) is constructed from spiralized tungsten-wire of diameter 13·5 μm, with a total wire length of 772 cm and a total resistance of approximately 3100 ohms at 0°C. The wire is supported on polytetrafluorethylene (PTFE) monofilaments stretched across an 8·9-cm diameter ring of resin-bonded fabric.

During its descent from heights above 70 km the sensor is subjected to various forms of heat transfer. A theoretical analysis of the different factors that contribute to the heat flow has been made by Hyson,[2] who concluded that during night flights, in the absence of solar radiation, the only major source of error in the indicated temperature was caused by dynamic heating.

In order to determine the various temperature corrections to be applied, experiments had been conducted during 1963, before the first rocket soundings, in the low-density wind-tunnel of the National Physical Laboratory (Clark[3]), but most of the measurements were taken at wind speeds in excess of the fall-speed of the sonde at the appropriate pressures. Further wind-tunnel experiments have been performed recently over a larger range of pressures and at more representative wind speeds. In addition, measurements of the rate of energy transfer by convection were made and tests were conducted in a laboratory vacuum chamber to determine the radiation characteristics of the sensor.

Wind-tunnel experiments. For the purpose of the wind-tunnel experiments one sensor was mounted on a rotatable base, as used by Clark,[3] and placed in the working chamber of the tunnel with a second identical sensor mounted in the stagnation chamber, the pressures in the two chambers being measured by a Pace gauge and a precision oil-gauge respectively. In addition, a McLeod gauge was used as a standard to calibrate the recording gauges before each run, when the pressure in the two chambers was equal; a further comparison was made at the end of each run. When any appreciable drift of the gauges occurred the readings were not accepted, but this was infrequent.

The normal fall-speed of the sonde and parachute decreases from about 150 m s^{-1} at 62 km to 65 m s^{-1} at 50 km and 31 m s^{-1} at 40 km and it is in the region above 50 km that the temperature sensor experiences the greatest effect from dynamic heating. Thus the tests were conducted over a range of airspeeds to include the above descent rates at the appropriate pressure levels. Most of the investigations were carried out at pressures of 80, 160, 320, 500 and 1000 μmHg, corresponding to approximate heights of 61, 56, 50, 47 and 42 km, with a small number of tests at 1500, 2000 and 3000 μmHg; the pressure equivalents in millibars are given in Table I. At the higher pressures the limitations of the wind-tunnel pumps prevented speeds other than about 50 m s^{-1} from being obtained.

The simplified energy balance equation of the sensor is

$$E + Du^2 = k\,(T_i - T)$$

where E is the energy supplied to the sensor; D is a dynamic heating coefficient and is probably a function of u and T and pressure, p, of the working chamber; and $k = k_c + k_r$ where k_c is the coefficient of convective heat transfer and k_r is a radiation coefficient. The observed stagnation and working pressures enable values of the airspeed, u, and the ambient temperature, T, of the working chamber to be calculated; T_i, the indicated air temperature,

TABLE I—HEAT-FLOW AND ASSOCIATED PARAMETERS OF THE SENSOR DURING DESCENT

p	p	$\rho \times 10^3$*	H(U.S.)*	u	$u^2 \times 10^{-4}$	$k \times 10^3$	$D/k \times 10^4$	Du^2/k	ΔT_r	ΔT_s	C/k
μmHg	mb	kg m^{-3}	km	m s^{-1}		J s^{-1}K^{-1}	K m^{-2} s^{-2}		degrees Kelvin		s
80	0·11	0·15	61	128	1·64	3·5	6·9	11·3	1·6	18·6	0·9
160	0·21	0·29	56	97	0·94	6	6·7	6·3	1·0	10·9	0·5
320	0·43	0·62	50·5	68	0·46	10	5·5	2·5	0·6	6·5	0·3
500	0·67	0·97	47	54	0·29	15	6·9	2·0	0·3	4·3	0·2
1000	1·33	2·06	42	37	0·14	25	9·7	1·4	0·2	2·6	0·1
1500	2·00	3·04	39·5	30	0·09	28	10·4	0·9	0·1	2·3	0·1
2000	2·67	4·17	37·5	25	0·06	34	10·7	0·6	0·1	1·9	0·1
3000	4·00	6·85	35	21	0·04	41	12·6	0·5	0·1	1·6	0·1

* Density, ρ, and height, H, values are based on the U.S. Standard Atmosphere 1966 for 60°N January (cold).

is measured directly. Figure 1 shows the values of $\Delta T = T_t - T$ plotted against u^2 for $p = 160$ μmHg and $E = 0$, and indicates a linear relationship, the gradient of which is D/k, the dynamic heating factor; Clark's[3] results from 1963 and Hyson's[2] theoretical curve for a cylinder in free molecular flow are also shown. Values of D/k for the various pressures and the dynamic heating correction Du^2/k, for normal sonde fall-speeds and heights based on the U.S. Standard Atmosphere 1966, are given in Table I. The effect of yaw was studied by repeating some runs with the sensor inclined at various angles to the airstream but this only confirmed the findings of Clark, that there is virtually no change in indicated temperature for angles of yaw up to 45°.

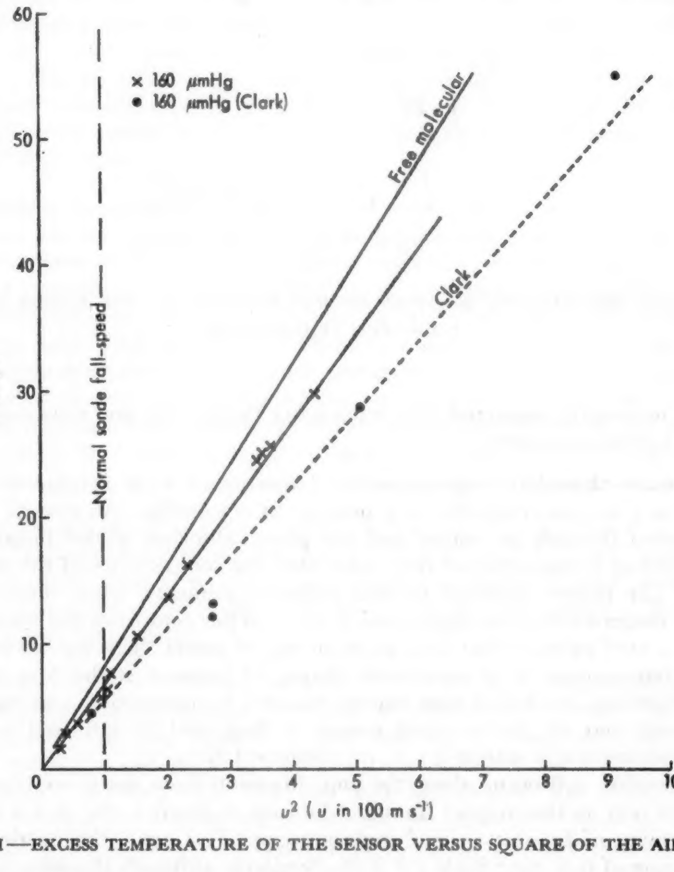

FIGURE 1—EXCESS TEMPERATURE OF THE SENSOR VERSUS SQUARE OF THE AIRSPEED

Electrical energy was also supplied to the sensor during each wind-tunnel test and the variation of T_t with E indicated a good linear relationship in almost all cases; examples are shown in Figure 2. At the lower pressures of 80 and 160 μmHg, where it was possible to obtain a large range of airspeeds, the value of $k = \mathrm{d}E/\mathrm{d}T_t$ varied only slightly with airspeed, but at higher pressures the value of k was more variable. Estimated values of k for normal sonde fall-speeds are given in Table I.

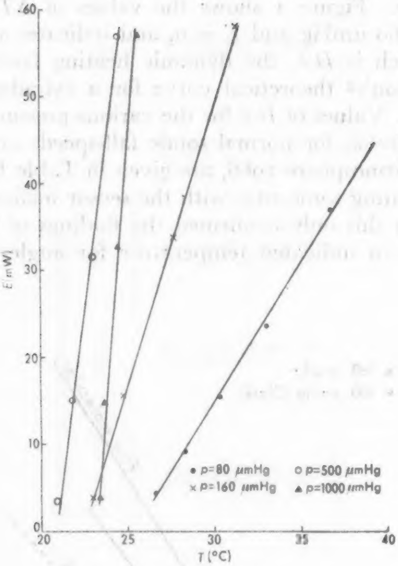

FIGURE 2—RELATIONSHIP BETWEEN ENERGY SUPPLIED TO THE SENSOR AND THE INDICATED TEMPERATURE

The tests were conducted over a period of three weeks and were not carried out in a systematic order.

Vacuum-chamber experiments. Experiments were conducted on the sensor in a vacuum chamber at a pressure of 0·3 μmHg. An electric current was passed through the sensor and the power absorbed varied linearly with the excess of temperature of the sensor over the temperature of the chamber walls. The power absorbed by four different elements, when there was an excess temperature of 30 degK, varied by ±20 per cent from the mean value of $9{\cdot}4 \times 10^{-3}$ joule s^{-1} but for a given supply of power there was no variation of the temperature for a reasonable change of pressure at this low pressure. It is therefore concluded that energy transfer by convection was negligibly small and that all the electrical energy is dissipated by infra-red radiation and conduction at a rate of $3{\cdot}1 \times 10^{-4}$ joule s^{-1} K^{-1}.

Conduction will occur along the monofilaments from the outer ring of the tungsten wire to the support frame, a distance of about 1 cm. For a thermal conductivity of $\lambda = 2{\cdot}5 \times 10^{-3}$ joule s^{-1} cm^{-2} K^{-1} cm^{-1} the conduction is at the rate of 6×10^{-5} joule s^{-1} K^{-1}. Similarly although the wire is almost isothermal, some conduction will occur at the two ends of the wire where it is connected to the terminal electrodes. For a distance of 1 cm at each end of the wire and $\lambda = 1{\cdot}70$ joule s^{-1} cm^{-2} K^{-1} cm^{-1} the rate of conduction is $4{\cdot}8 \times 10^{-6}$ joule s^{-1} K^{-1}. Thus the rate at which energy is dissipated by conduction is small compared with the total rate of energy dissipation. If the mean value of $9{\cdot}4 \times 10^{-3}$ joule s^{-1} is adopted as the energy dissipated when the temperature of the wire is 30 degK above the chamber wall temperature

of 295 K, and equate this with $\varepsilon A_\varepsilon\sigma(325^4 - 295^4)$, where σ is the Stefan-Boltzmann constant, the value of the effective emission constant of the sensor $\varepsilon A_\varepsilon = 0{\cdot}46$, where ε is the emissivity and A_ε the effective radiating area of the sensor. It is difficult to obtain an accurate value of A_ε because some parts of the radiating surface will be shadowed by others and there will be some emission from the PTFE monofilaments, but a good estimate would be $A_\varepsilon = 3$ cm^2 from which we deduce $\varepsilon = 0{\cdot}15$. However, it is the value of $\varepsilon A_\varepsilon$ which is important since it represents the effective emission constant of the complete sensor.

The sensor was next exposed to short-wave radiation from a quartz-iodine lamp through the window of the chamber and the radiation flux was measured by substituting a solarimeter for the sensor. It was found that for a radiation flux of $18{\cdot}6 \times 10^{-3}$ joule s^{-1}cm^{-2} the excess temperature was 28·7 degK giving a value of $\alpha A_\alpha = 0{\cdot}48$ where α is the absorption coefficient and A_α the effective absorption area of the sensor. When the plane of the element is normal to the radiation the effective absorption area of the sensor is about 0·67 cm^2, from which $\alpha = 0{\cdot}72$.

Radiation corrections. If we use the values of $\varepsilon A_\varepsilon$ and αA_α obtained above and assume that the sensor is in long-wave radiation equilibrium with the atmosphere below, but emits freely upwards, values of the infra-red radiation correction, ΔT_r, to be added can be obtained. The rate of emission of infra-red radiation is $\frac{1}{2}\varepsilon A_\varepsilon\sigma T_i^4$ where T_i is the indicated air temperature at a given level. Values of $\Delta T_r = \frac{1}{2}\varepsilon A_\varepsilon\sigma T_i^4/k$ given in Table I are based on temperatures from the U.S. Standard Atmosphere. The radiation correction. ΔT_s, due to incident solar radiation on the sensor is $0{\cdot}48S/k$, where S is the radiation flux in joule s^{-1}cm^{-2}. If albedo effects are neglected and a value of $S = 136 \times 10^{-3}$ joule s^{-1}cm^{-2} is used, the corrections are as shown in Table I.

Time constant. The time constant of the sensor is C/k where C is the thermal capacity of the sensor and has a value of about 3×10^{-3} joule K^{-1}. From the values shown in Table I it can be seen that the sonde would fall about 115 m in 0·9 s at a height of 61 km. The lag of the sensor is thus quite small and can be neglected.

Conclusion. It is evident from Table I that the greatest single correction to be applied during daylight soundings is that caused by solar radiation. The amount of heating caused by solar radiation incident on a sensor will vary according to the angle of insolation, the albedo and the effective area of the sensor receiving solar radiation at a given time; this is particularly difficult to estimate because on its descent the parachute oscillates causing the angle of incidence to vary continually. Shading will also occur from the parachute. Corrections to be applied due to solar radiation are therefore difficult to determine and for this reason the British Meteorological Office only conducts rocket soundings during the hours of darkness, when the only major correction to be applied is that caused by dynamic heating.

Acknowledgement. The authors would like to thank the staff of the National Physical Laboratory Aerodynamics Division for providing the facilities of their low-density wind-tunnel.

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REVIEWS

Forecast for Overlord — June 6, 1944, by J. M. Stagg, C.B., O.B.E. 238 mm × 160 mm, pp. 128, *illus.* Ian Allan Ltd, Shepperton, Surrey. 1971. Price: £2·60.

This is a most valuable and absorbing book. Its value springs from its full and dispassionate account, given by the man who was at the centre, of a particularly critical aspect of the invasion of Europe which took place on 6 June 1944 and was known by the code name Overlord. Operation Overlord was on such an enormous scale and of such vital consequence it will always have its place among the few decisive events in all history. A powerful group of nations had decided to stake almost everything, if not everything, upon the success of this operation. The outcome contained only two possibilities: either success which might take a long time to complete and consolidate, or rapid utterly calamitous failure.

But, except for one aspect, success was virtually assured by the weight of resources available and by the flexibility with which they could be deployed. The exception was the weather, the one thing no one could control, the one thing that could certainly bring disaster to what was the most completely planned military operation of all time. Apart from general readiness, there were numerous factors such as moon and tides to be taken into account and, subject to the weather, the most favourable combination of all these factors occurred in the first week of June 1944. An alternative period, but less favourable in several particulars, was the third week of that month. As it happened, the weather conditions in and around the English Channel during the early days of June, so far from illustrating the calm of summer, were stormy and overcast. As for the outlook, the meteorological situation was of such complexity and difficulty that the views of the best experts were bound to be divided. As D-day approached the task of Group Captain James Stagg as Chief Meteorological Officer to General Eisenhower, the Supreme Allied Commander, could not have been more worrying in regard to both the scientific judgements he had to make and the extreme importance of the advice he had to give. After the event, but not at the time, it is gratifying to note that the circumstances of great events are often so fashioned as to exact greatness from the principal characters — and in this particular great event let there be no doubt that Stagg was a principal.

The book is absorbing because it deals comprehensively with one of the important ingredients of a major historical occasion. Stagg was appointed to the Supreme Commander's staff in November 1943 and all his e

were geared to the production of the D-day forecast some seven months later. Team-work had to be developed because many meteorologists, British and American and others, were involved with the various naval, army and air forces taking part in Overlord. These meteorologists each had their special problems, according to the role assigned to the military formation they were serving. There were also the Central Forecasting Office of the Meteorological Office at Dunstable, that of the Admiralty in London and that of the United States Army Air Force at the Widewing Headquarters in Teddington, Middlesex. Facilities were therefore provided for telephone conferences as frequently as necessary with all these centres simultaneously, each participant having his own charts in front of him and able to give his own views to all the others and to listen to the views they expressed. Stagg had to distil all these opinions, together with his own, into a forecast for the Supreme Commander. The procedure was tested at regular intervals, sometimes in connection with exercises, and one notes with interest the author's comment that in the whole series of conferences unanimity on a complete forecast was never achieved.

A special reason for welcoming this book is that in other published histories of the 1939–45 war the weather aspects of D-day are seldom presented adequately. In some cases it is clear that these aspects were not understood, in others attempts are made to dramatize individuals whereas the weather itself contained all the drama that anyone could wish for. Stagg's account is no less fascinating for the non-meteorologist than for the meteorologist. In it we see weather forecasting in its wide operational context and can perceive the responsibilities and anxieties of commanders as well as advisers. The decision to postpone D-day from 5 to 6 June because of the weather conditions is fully described with the aid of synoptic charts and it is seen that 6 June was the one day in the month of June when Overlord could have been launched.

A feature of the book is the generous acknowledgement which Stagg makes to the other meteorologists who participated with him, either in the telephone conferences or in other ways, in framing the weather forecasts for the operation. He insists that what he did was the culmination of team effort and, as we read on, the familiar names of some of the great forecasters pass before us. However, let us not conspire with the author in submerging his own contribution. James Stagg was the central figure in this significant element of a most momentous event. He carried the main weight of responsibility and the forecast, which did not represent the majority view, was highly accurate in a situation of the utmost difficulty.

P. J. MEADE

Standard dictionary of meteorological sciences — English–French/French–English, by G.-J. Proulx. 254 mm × 190 mm, pp. xxix + 307. McGill-Queen's University Press, 70 Great Russell Street, London WC1, 1971. Price: £9·50.

This beautifully produced but rather expensive dictionary, aimed not only at the meteorologist but at users in other disciplines, contains too many expressions. It would be more useful if confined to purely meteorological

and associated hydrological/oceanographical terms and idiomatic expressions; as it is there is a superabundance of adjectival expressions that are obvious and are not required.

Due acknowledgements and references are given in the preface to the *Meteorological glossary* (London, HMSO, 1963) and to the *International cloud atlas* and *International meteorological vocabulary* of the World Meteorological Organization as well as to the American Meteorological Society's *Glossary of meteorology*. In addition a selected English-language and French bibliography is given. No reference is made, presumably because of timing, to G.-O. Villeneuve's *Glossaire météorologique* published earlier in 1971 by the Quebec Meteorological Service and to which this dictionary is complementary.

The French preface amplifies the various sections into which meteorology is divided and draws attention to other disciplines involved.

It is, however, excellent for the names of local weather phenomena, particularly winds, and the author has been very industrious here. Included are the caver — a Hebridean breeze, the doister or dyster — a gale off the sea, the haar, and so on throughout the world, to the vent d'autun of southern France, and the youg — a warm Mediterranean wind. I had hoped to find 'pied de vent' but unfortunately no, in fact these phenomena, being mostly the same in English and French, are more suited to a glossary.

Also it is very useful to have the English/French, French/English titles and abbreviations of the various meteorological and allied organizations under the one cover.

In general it is certainly a dictionary that every meteorological library will be expected to have on its shelves.

H. H. de CARLE

Kuwait: urban and medical ecology, by Geoffrey E. Ffrench and Allan G. Hill. 303 mm × 215 mm, pp. xiii + 124, *illus.*, Springer-Verlag, 1 Berlin 33, Heidelberger Platz 3, Berlin-West, 1971. Price: DM 58.

Described as a geomedical study this account of the State of Kuwait gives emphasis to sociological and economic developments, and contains a wealth of detail about health and disease, but only devotes some three pages to the climate. However, the statistics given, based mainly on the observations at the Government station of Shuwaikh (29°20′N 47°57′E) for the period 1956–69, but also including temperature and rainfall graphs for three other climatological stations as well as for the International Airport for the period 1956–69, adequately portray the essential features of sporadic winter rainfall, very hot dry summers and an extreme overall range of temperature (−3°C to +49°C for the 10-year period). Monthly wind roses for the Airport (period?) show clearly the north-westerly wind (shamal) which predominates at all times of the year. No mention is made of the earlier observations made by the India Meteorological Department and published in *Tables of temperature, relative humidity and precipitation for the world, Part V* (London, Meteorological Office, 1958) which gave an annual average rainfall of 129·5 mm at Kuwait City compared with the 1956–69 average of 102·4 mm at Shuwaikh. In a

desert region rainfall is of course notoriously variable, but the excavation on the island of Failaka of a well-established bronze-age settlement — old perhaps when Babylon was new — as well as the remains of the flourishing 4th century B.C. Greek colony of Ikaros, suggests that over the past 3000 years the climate of Kuwait has become progressively less hospitable.

F. E. DINSDALE

NOTES AND NEWS

Retirement of Mr L. Jacobs

Mr Lewis Jacobs joined the Office as a Technical Officer in 1936. For the next 20 years he was engaged in forecasting or in the organization of forecasting services. He first served at Royal Air Force stations at home and then spent 3 years lecturing and forecasting for the General Reconnaissance School in Canada during the war, returning to England to become Senior Meteorological Officer with Airborne Forces in 1944. In 1945 he was awarded the United States Medal of Freedom with Bronze Palm for his services to the 1st Allied Airborne Army. He was mobilized as a wing commander in 1945 and later served in the Azores, returning, on his release from the RAFVR in 1947, to become one of the senior forecasters at the Central Forecasting Office at Dunstable. In 1950 Mr Jacobs became Senior Meteorological Officer at Gloucester. During 1956/57 Mr Jacobs represented the Director-General on a small committee responsible for planning the new headquarters building at Bracknell.

In 1957 Mr Jacobs was promoted to Assistant Director in charge of observatories and micrometeorology, remaining in this post for 12 years. During this period he was an active member of national and international committees on geomagnetism, atmospheric electricity and solar and terrestrial radiation and wrote several scientific papers on these subjects. The *Observatories' Year Book* had been discontinued at the outbreak of the war in 1939 and from 1957 onwards Mr Jacobs undertook the mammoth task of editing and publishing the back numbers of this annual, bringing it up to date with the volume for 1967 when responsibility for seismology and geomagnetism was transferred to the Institute of Geological Science, Natural Environment Research Council.

Since 1970 Mr Jacobs has been Assistant Director in charge of climatological services. Here his persistence and flair for organization have resulted in arrangements for the analysis by prison labour of autographic climatological records; by this means it is hoped to work through a very large backlog of useful records which would otherwise remain untouched.

Mr Jacobs has had wide interests and responsibilities in the Meteorological Office; as well as the activities mentioned above he prepared several climatological memoranda one of which, prepared during the war, helped the planning for the layout of runways at London /Heathrow Airport.

Mr Jacobs retired on 14 February 1972, and his colleagues will not be surprised that he has now turned his zeal and energies to teaching mathematics in a Grammar School near his home. We wish Mr Jacobs and his wife many happy years of retirement.

J. K. BANNON

LETTER TO THE EDITOR

Lightning strikes

We were interested to see Mr Pilsbury's account in the *Meteorological Magazine* for December 1971, pp. 373–375, of the lightning strike on the tree near the Meteorological Office. Of particular interest to us was the sizzling noise reported by Mrs Gaines. At Tarrant Rushton, Dorset, in 1953, we saw lightning strike a low building and a small tree about 150 yards from the office window through which we were looking. There was a noticeable sizzling which we heard immediately before the strike. It seemed to come from the air through which the lightning passed and not from the objects struck.

Meteorological Office, Bracknell

S. G. CORNFORD K. BRYANT

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